NAL PROPOSAL No. 0135

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PROPOSAL FOR AN EXPERIMENT TO STUDY THE REACTION $K^- p \to \bar{K}^0 n$ AT NAL ENERGIES

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Proposal for an Experiment to Study the Reaction

$K^- p \rightarrow \bar{K}^o n$ at NAL Energies

We propose to measure $d\sigma/dt$ for $K^- p$ charge exchange from t=0 to $t = -1 (BeV/c)^2$ at laboratory energies ranging from 30 BeV to the highest attainable beam energies. The purposes for doing the experiment are:

1. The check the validity of the Pomeranchuk-Okun' rule through the sensitivity of this reaction to the difference between $K^- p$ and $K^- n$ total cross sections.
2. To test the Regge pole predictions for this reaction which are based on ρ and A_2 exchange.

The experimental arrangement consists of a hydrogen target almost totally enclosed in an anti-house and scintillation counters and wire chambers to detect the decay of the K^o_s. We propose initially to run at 30, 55 and 80 BeV with a beam of 10^6 particles/pulse with $\Delta p/p$ of .5%. The 15 Mv beam in area 2 would be suitable and would provide a K^-/π^- ratio of a few percent. We also propose to make a run with deuterium in the target to investigate the reaction $K^- + d \rightarrow \bar{K}^o + n + n$ in order to prepare for a future experiment on $K^+ + d \rightarrow K^o + p + p$. The requested allotment will allow an accumulation of several thousand events at each energy setting and adequate tune-up time.

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I. Theoretical Motivation for the Experiment

A. Test of the Pomeranchuk-Okun' Rule.

The experiments of Allaby et al.,[1] (Figure 1) indicate sizable differences remaining at Serpukhov energies between K^-p and K^-n total cross sections. The prediction that $(\sigma_{K^-p})-(\sigma_{K^-n}) \rightarrow 0$ as lab energy goes to infinity is known as the Pomeranchuk-Okun' rule[2]. It implies that at asympototically high energies total cross sections are independent of isotopic spin or, stated another way, that all charge exchange cross sections should vanish at high energies. The prediction that $(\sigma_{K^+p})-(\sigma_{K^-p}) \rightarrow 0$ at infinite energy is well known as the Pomeranchuk theorem[3] which states that particles and anti-particles on the same target should have the same cross sections.

The Serpukhov cross section differences mean either that the two theorems are violated in the K-nucleon system or that asymptotic energy has not yet been reached.

By the optical theorem and charge independence, differential $K^-p \rightarrow \bar{K}^0 n$ charge exchange in the forward direction is given by

$$\frac{d\sigma}{dt}_{t=0} = \frac{\pi}{k^2}\left(\mathrm{Real}(K^-p)-\mathrm{Real}(K^-n)\right)^2 + \frac{1}{16\pi}\left(\sigma(K^-n)-\sigma(K^-p)\right)^2$$

where $\mathrm{Real}(K^-p)$ and $\mathrm{Real}(K^-n)$ are the real parts of the elastic forward scattering amplitudes of the respective reactions.

Present data are consistent with the real parts being zero. Thus a measurement of $d\sigma/dt$ at t=0 is likely to provide a sensitive, null test of the equality of $\sigma(K^-n)$ and $\sigma(K^-p)$. The difference in the two total cross sections is measured directly in a single experiment instead of in two separate experiments, and there are no Glauber corrections to consider as there are in deuterium target experiments (necessary to measure $\sigma(K^-n)$).

K^-p charge exchange is a test of the Pomeranchuk-Okun' rule rather than the Pomeranchuk theorem. In π^-p charge exchange, both theorems apply since π^- and π^+ are antiparticles. K_s^o regeneration experiments test only the particle-antiparticle theorem. Thus K^-p charge exchange is a separate piece of information necessary together with the regeneration experiment for an understanding of possible Pomeranchuk violating effects in the K- nucleon system. If the Pomeranchuk-Okun' rule were violated it would mean that vacuum (i.e., I=0) exchange could not dominate high energies.

B. Regge Pole Predictions

Fits to existing K^-p charge exchange data can be made on the assumption of ρ and A_2 exchange and exchange degeneracy (Phillips and Rarita).[4] The phases of the ρ and A_2 are such that the $K^-p \to \bar{K}^on$ amplitude dominated by the imaginary part[5]. Comparison of the data with measured values of K^-p and K^-n total cross sections bears this out (Figure 2). If this remains so at higher energies, $K^-p \to \bar{K}^on$ at $t=0$ is truly a measure of $\sigma(K^-p) - \sigma(K^-n)$. Thus if $d\sigma/dt_{t=0}$ does not go to zero $\sim 1/p_{lab}$ as predicted by ρ exchange, but persists at high energy, this would be an indication not only of a Pomeranchuk-Okun' violation, but also of some strange non-Regge behavior. One model of how such a violation might occur has been calculated by Barger and Phillips[6] (Figure 3).

We also propose to measure $d\sigma/dt$ out to $t = -1$ $(BeV/c)^2$. These data should be of considerable interest, for example in testing other predictions of Regge Pole models.

C. Deuterium Run

The Regge Pole model, with ρ and A_2 exchange degeneracy, predicts equal K^-p and K^+n charge exchange cross sections. In addition, SU_3 symmetry results in the sum rule $(K^-p \rightarrow \bar{K}^0 n) + (K^+n \rightarrow K^0 p) = (\pi^-p \rightarrow \pi^0 n) + 3\,(\pi^-p \rightarrow \eta n)$ for both differential and total cross sections. Consequently, a self consistent test of the asymptotic Regge SU_3 predictions can be achieved only with the measurement of <u>all</u> four charge exchange processes. The K^+n charge exchange reaction is usually studied with a deuteron target. In this case the observed reaction $K^+d \rightarrow K^0 p$ must be corrected (40% for $-t \leq 0.1$ GeV/c^2) for the presence of two nucleons in the final state. The precise value of the correction depends on the knowledge of the relative size of the spin-flip and non-spin-flip amplitudes. Since this is unknown at high energies, it is assumed that the charge exchange scattering is predominately non-spin-flip.

We propose runs at 30 and 80 GeV/c with a deuterium filled target. In this way the reactions $K^-p \rightarrow \bar{K}^0 n$ and $K^-d \rightarrow \bar{K}^0 nn$ can be compared directly. It is crucial to determine experimentally how well accurate charge exchange cross sections can be extracted from deuterium under conditions in which a direct calibration is available. It is apparent that the triggering and detection systems remain unchanged for these runs.

Monte Carlo calculations show that smearing of the $\bar{K}^O$ momentum because of nucleon Fermi motion will not seriously impair the kinematic constraints applicable to the K^-p charge exchange reaction.

II. Previous Experiments on $K^-p \rightarrow \bar{K}^On$

The present experimental data obtained by the CERN-ETH spark chamber group (Astbury, et al[7]) together with the Regge Pole fits of Phillips and Rarita are shown in Figure 4.

III. Experimental Method

Figure 5 is a plan view of our proposed experimental arrangement. It shows our apparatus located in the final 15 mr beam enclosure. The essence of our method is to surround a hydrogen target with a series of counters to veto charged particles and gamma rays. Then the downstream trigger scintillators will detect neutral particles that decay outside the target box,for example $K^O_s \rightarrow \pi^+ + \pi^-$. The large spacing between the last two chambers is to make possible an accurate measurement of the π^+ and π^- angles in the lab in order to make a precision reconstruction. Wire spark chambers of conventional design will be used to make these measurements, although it may be necessary to deaden them on the beam line. Negative Kaons are selected by gas Cerenkov counters with appropriate thresholds; hodoscopes of scintillation counters will measure the trajectory of each incoming beam particle. Whenever a K^- signature is received from the threshold counters along with a trigger scintillator pulse and no anti pulse, the track locations in the beam hodoscopes and wire chambers are read into an on-line PDP-8/E computer.

We propose to place our hydrogen target in the last 15 mr beam enclosure at a point just beyond a 2½' step in the floor elevation. The beam at this point will be about 4 feet off the floor and 20 inches from the wall. This will provide sufficient room for the target box. The widening of the enclosure as it enters the meson building provides adequate clearance for the downstream wire chambers. A pair of quadrupole magnets at the upstream end of the enclosure can reduce the beam spot size at the experiment to an acceptable value.

Some parameters of our set-up in the 15 mr beam are as follows:

LH_2 target length	3 feet		
Length of experiment	$L=E_{beam}$; E in BeV, L in feet.		
Wire chamber size	Largest is 3 feet square, rest scaled accordingly (subtends an angle of 50 mrad at the target)		
Beam rate	10^6 particles/pulse		
Beam length (production target to experimental target)	1310 feet or slightly less than two K^- decay lengths at 30 BeV.		
Fraction of K_1^o lifetimes covered	$\frac{2}{3}$		
Fraction of $\bar{K}^o$ decays to $\pi^+\pi^-$	$\frac{1}{3}$		
Fraction of true events surviving reconstruction cuts	0.75		
	30 GeV	55 GeV	80 GeV
K^-/π^- ratio at target	2%		6%
Event rate (per 24 hour day)	650	390	220
Proposed division of running time:			
for K^-p (3200 events each energy)	125 hours	200 hours	375 hours

Proposed division of running time:
(continued)

	Beam Energy		
	30 GeV	55 GeV	80 GeV
for K^-d (1600 events each energy)	65 hours		200 hours
tune up	200 hours		
Total requested time	1165 hours		

These event rates were computed on the assumption that the cross section is given by the formula $\sigma = \frac{7.3 \text{ mb}}{p^{2.1}}$ which is that given by Firestone, et. al[8] for $K^+d \rightarrow K^o pp$. This gives a more pessimistic estimate than a fit to the $K^-p \rightarrow \bar{K}^o n$ data which appears to go as $\frac{0.5 \text{ mb}}{p}$ from the existing data (See Figure 3).

B. Background Suppression

The backgound is of two types:

I) $K^- + p \rightarrow \bar{K}^o + n$ + extra neutral pion(s). These are events which produce a high energy K^o that fits two-body kinematics and at least one additional π^o that escapes detection by the anti-counters.

II) Reactions with neutrals like:

A. $K^- + p \rightarrow \Xi^o + K^o$

B. $K^- + p \rightarrow K^o + \bar{K}^o + \Lambda^o$

Events of type I are most dangerous if the π^o is low energy. We plan to anti these events with very high efficiency by constructing a heavy liquid or lead glass Cerenkov counter with which to surround the target in all but the forward direction. This counter will have very poor efficiency for neutrons from $K^- + p \rightarrow \bar{K}^0 + n$ and about six radiation lengths for converting the gammas from neutral pions.

Events for type II-A are accompanied by a slow Ξ^0 which can not escape the anti house around the target. If events of type II-B include a slow Λ^0 they will be vetoed also. If the Λ^0 is detected and the K^0's escape, this can trigger the system but is very unlikely to reconstruct properly. Various angular cuts on the data can be used to check for and eliminate the presence of Λ^0's.

The total cross section for reactions II-B is 50 μb at 6 BeV/c.[9] As one goes to higher energy one would expect the "backward" portion of this cross section (i.e. where the Λ receives much of the beam momentum) to diminish rapidly. Therefore, we do not expect this to produce a serious contamination.

C. Reconstruction

The events can be completely reconstructed, even though no magnet is involved, by measuring the angles of the K_s^0 decay pions. We considered the use of a magnet but do not feel that it contributes enough to background suppression to warrent the necessary effort, expense and loss of solid angle. Constraints in reconstruction are that the decay is $K_s^0 \rightarrow \pi^+ + \pi^-$, that the K_s^0 lies in the decay plane and intersects the beam line, and two body kinematics. Each event is once over determined (one constraint fit) except for a small percentage of events whose decay plane is close to the production plane.

In order to test the feasibility of performing the experiment without a magnet, a Monte Carlo program was carried out in which randomly generated events were run through a simple reconstruction program. The program was carried out for 30 BeV incident K^- and assumed measurement errors of $\pm$ .5 mm in the wire chambers and a momentum spread of .5% in the beam. Three types of events were generated with a flat momentum transfer (t) distribution; 1) $K^- + p \rightarrow \bar{K}^o + n$; 2) $K^- + p \rightarrow \bar{K}^o + X$; 3) $K^- + p \rightarrow \Lambda + X$. In case (3), the Λ was reconstructed as though it were a K^o. Two cuts were applied to the random data in order to remove all the Λ events. The first cut required all the events to satisfy a one constraint fit which is lost if the decay plane is too near the production plane. The second cut required that the K^o decay asymmetry not be greater than a certain value. These cuts removed 40% of events of type 1). Figure 6 is a plot of these events versus t and shows no appreciable bias is introduced by these cuts. Figure 7 is a plot of reconstructed events of type 2) and shows the mass resolution of the system. The missing mass was generated with a flat distribution from .9 to 5.0 BeV.

The length of the experimental layout is chosen so that the direction cosines of the K^o decay products and the beam particle direction can be measured to an accuracy of about one percent, assuming a location accuracy of $\pm$ .5 mm in the chambers. This gives $\Delta t = .02\ t$ for most of the data.

D. Beam Particle Identification

It is necessary to reduce the contamination of π^- in the beam to a few percent of the K^- flux. Threshold counters are quite adequate. Since 150 feet of space are available in the tunnel enclosure they pose no problem since they are low pressure devices and are easy to construct and operate.

IV. Available Equipment

We can furnish all the equipment for the experiment except the hydrogen target. The target would be of standard design with no special features. Owing to the location it should probably be a refrigerated target. The target flask would have a volume of 1.2 liters. We have available all the electronic logic and wire chamber read-out equipment, a PDP-8/E computer, phototubes and scintillators and have facilities for constructing magnetostrictive chambers. We are willing to construct the necessary threshold beam Cerenkov counters, and help in tuning and developing the beam.

V. Equipment to be furnished by NAL

We would require construction of a liquid hydrogen target, and a time allotment on the PDP-10 computer for off-line analysis of the data. Our requirements for PDP-10 time could be as little as one or two hours for the purpose of doing simple checks of the data as they come from the experiment or as high as 35 hours for a fairly thorough analysis.

References

1. Allaby et al., Phys. Letters 30B (1969), 500.

2. I.Ia. Pomeranchuk, Soviet Phys. - JETP 3, 306 (1956).
   L. B. Okun' and I. Ia Pomeranchuk, Soviet Phys. - JETP 3, (1956), 307.

3. I. Ia. Pomeranchuk, Soviet Phys. - JETP 7, (1958), 499.

4. R. J. N. Phillips and W. Rarita, Phys. Rev. 138 (1965), B723; and 139 (1965), B1336.

5. D. Cline, J. Matos and D.D. Reeder, Phys. Rev. Letters 23, 1318 (1969).

6. V. Barger and R.J.N. Phillips, Phys. Rev. D 2 (1970), 1871.

7. P. Astbury et al., Phys. Letters 16 (1965), 328; and 23 (1966), 396.

8. A. Firestone, G. Goldhaber, A. Hirata, D. Lissauer, and G.H. Trilling, Phys. Rev. Letters 25, 958 (1970).

9. D. G. Scotter, et al., Nuovo Cimento 62A (1969), 1057.

Figure Captions

1. Total cross section data on K^-p and K^-n from Allaby et al.[1]

2. $(d\sigma/dt)_{t=0}$ versus K^- laboratory momentum, p_{lab}, for the reaction $K^-+p\rightarrow\bar{K}^0+n$ from Astbury et al.[7]

3. Predictions for $(d\sigma/dt)_{t=0}$ based on conventional ρ and A_2 Regge poles (solid line) and Pomeranchuk theorem violation (dashed curve), from Barger and Phillips.[6]

4. Data of Astbury et al.[7]

5. Plan view of proposed experimental layout.

6. Events cut from Monte Carlo data generated with a flat t distribution.

7. Distribution of successfully reconstructed events from $K^- + p \rightarrow K^0 + X$ where the mass of X has been generated with a flat distribution from .9 to 5.0 BeV.

8. Scatter plot of Δt versus $-t$ for a sample of reconstructed Monte Carlo events. Δt is the difference between the true t and the reconstructed t.

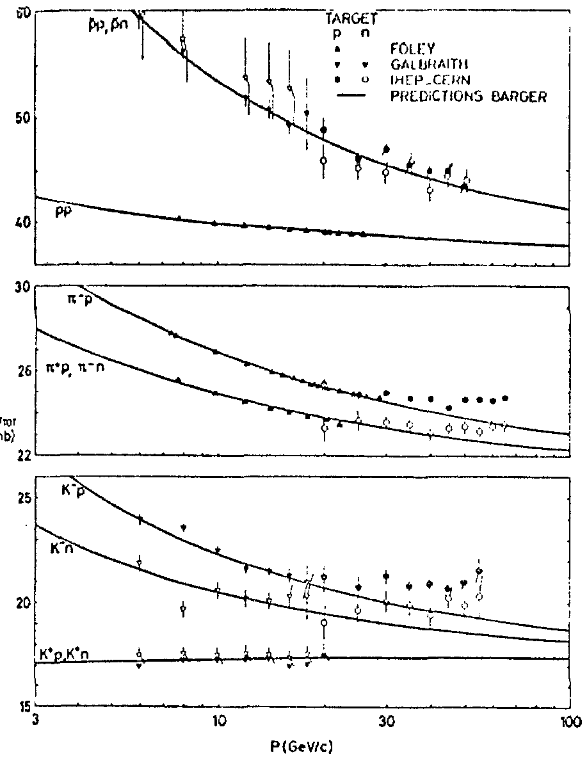


Fig. 1

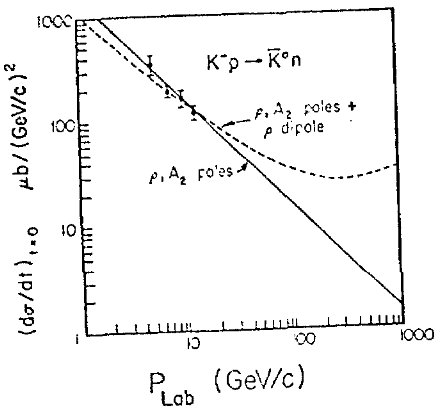


Fig. 3

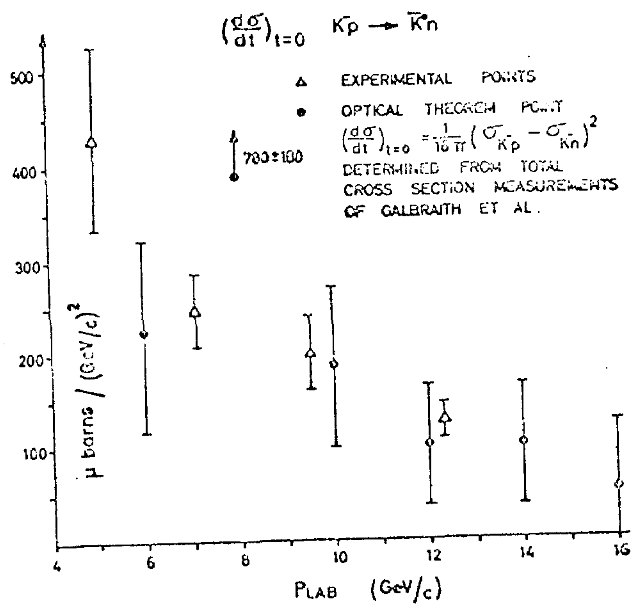
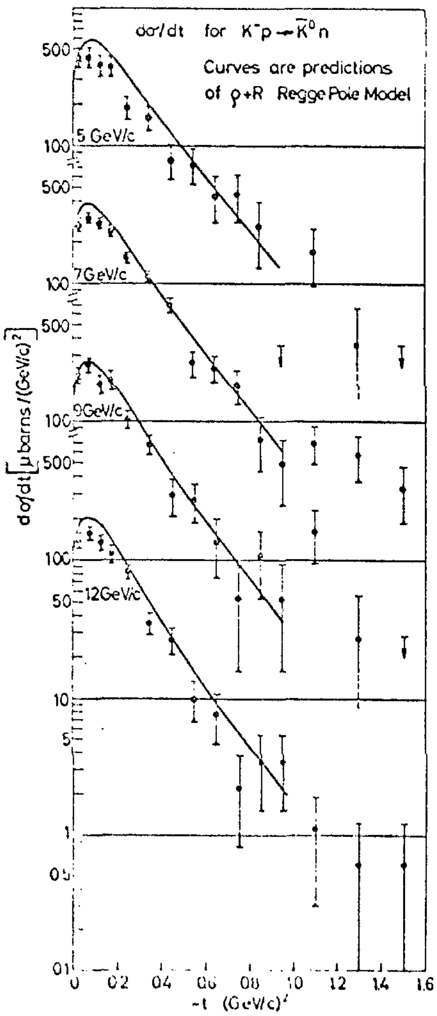


Fig. 2



$d\sigma/dt$ versus momentum transfer $-t$ at 5, 7, 9.5 and 12 GeV/c.

Fig. 4

Figure 5 Plan view of proposed experimental layout

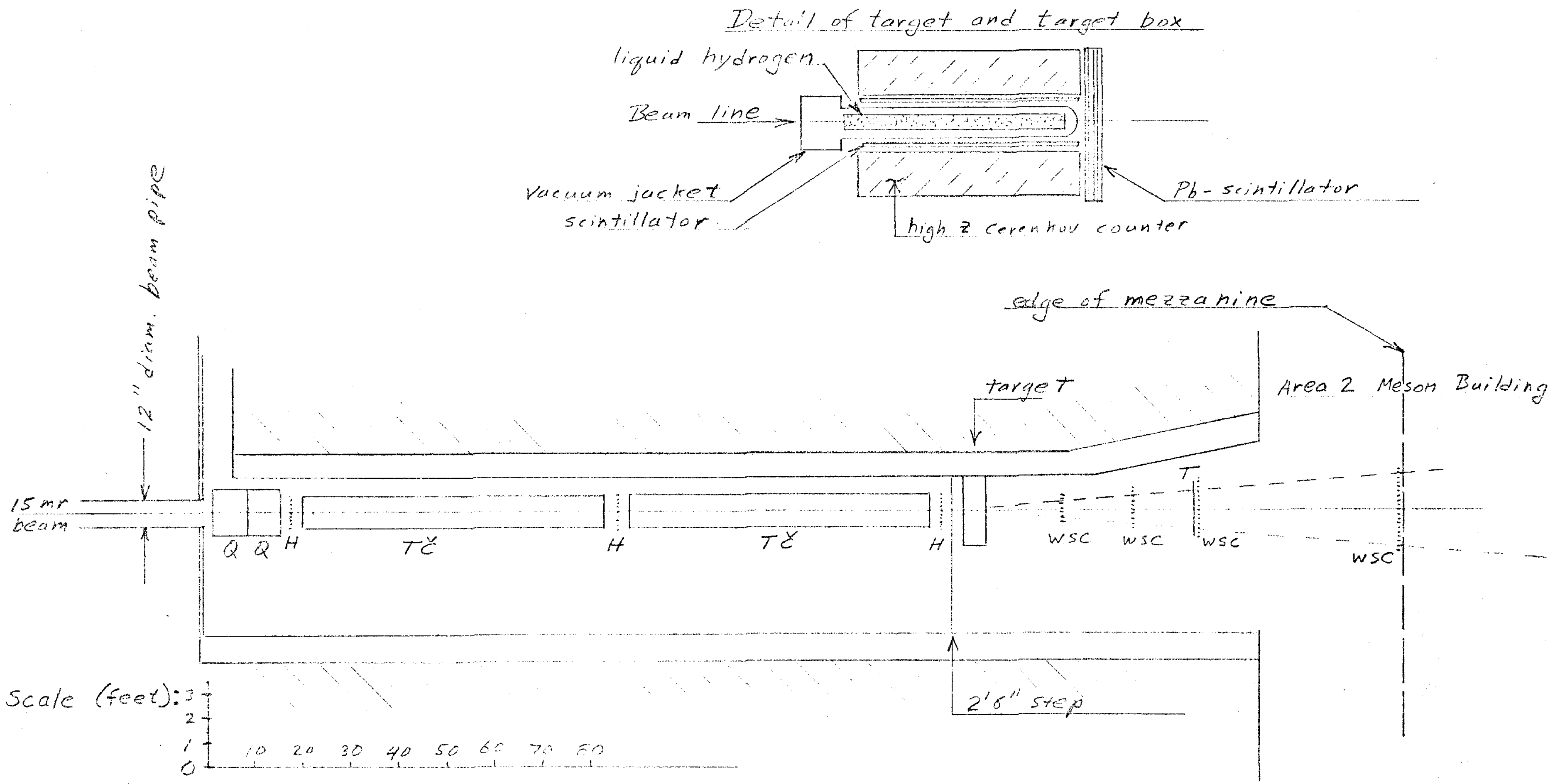
Q = quadrupole

H = beam hodoscope

TČ = threshold Cerenkov counters

WSC = wire spark chambers

T = trigger counters



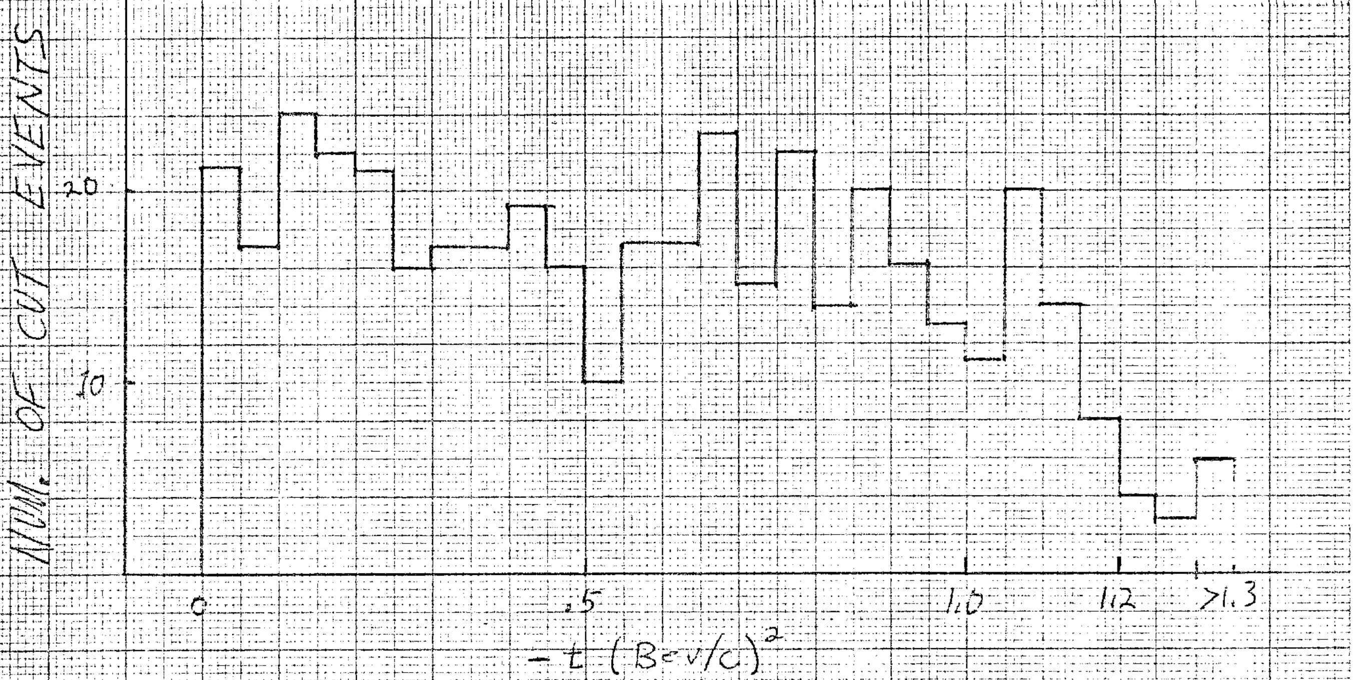


Figure 6

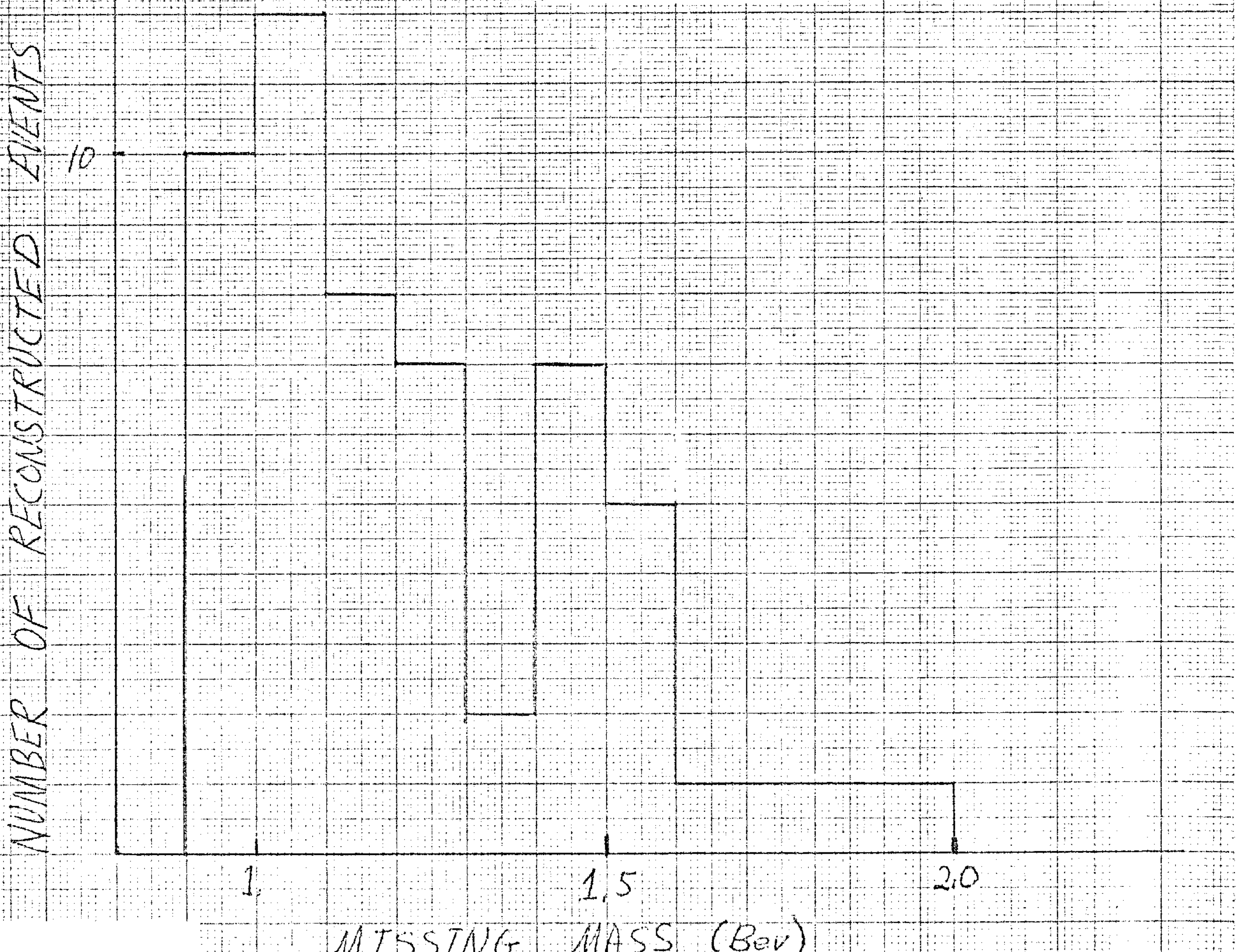
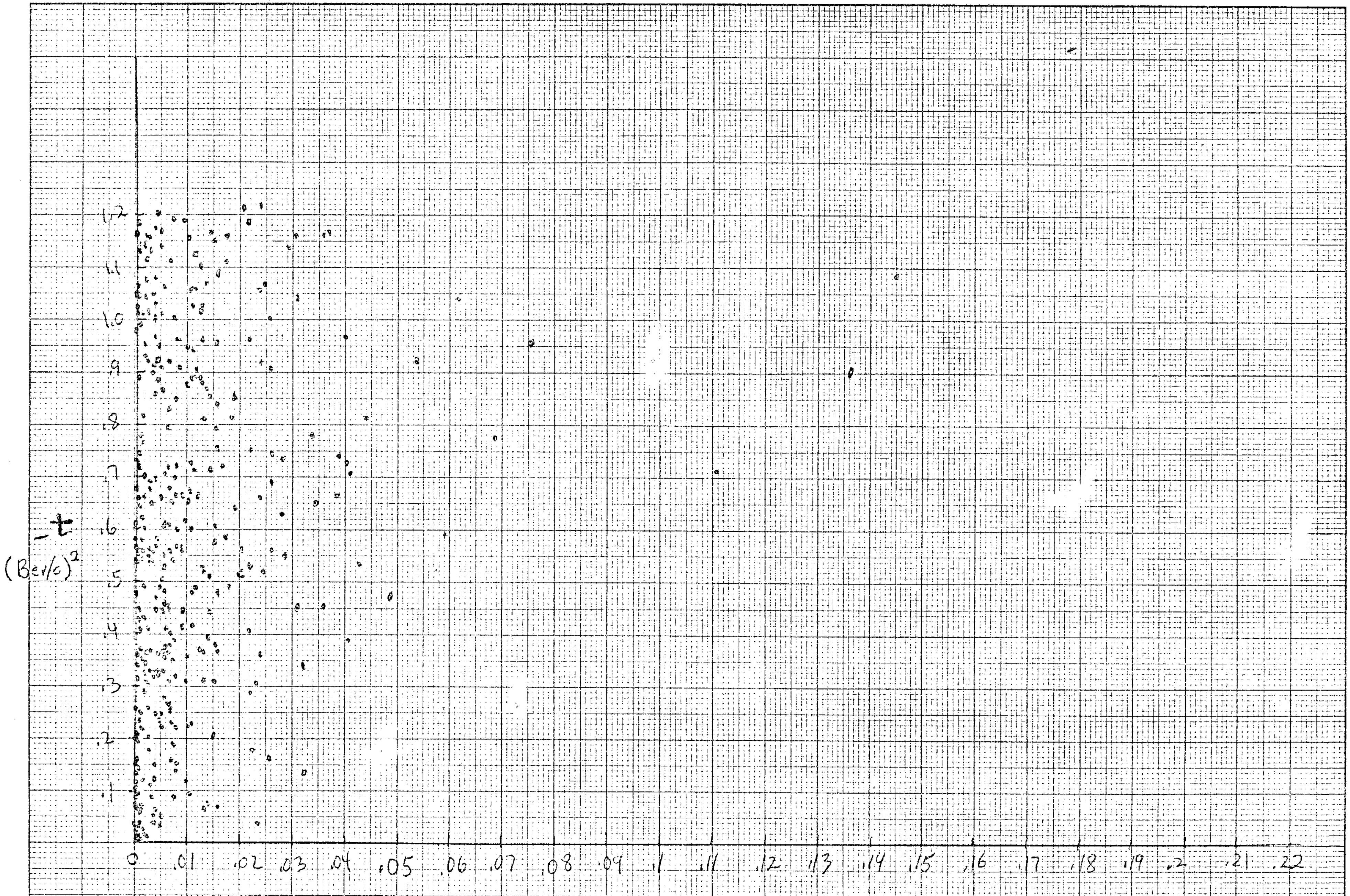


Figure 7



-t
(Bev/c)^2
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.11
.12
.13
.14
.15
.16
.17
.18
.19
.2
.21
.22
Δt (Bev/c)^2

Figure 8